A 3-D MODEL FOR OPTIMAL ALIGNMENT SEARCH SYSTEM OF HIGHWAY DESIGN BY EXTENDED DIGITAL MAPPING DATA

Seiichi KUSANO[1], Hidetoshi TAKAHASHI[2], Motoya YAMASAKI[3], Toshio TERAO[4], Norio TASHIRO[5], Thea Hack LORENTZEN[6], Minoru IMAI[7], Takayuki FUKASE[8]

[1]Civil Engineer, Central Nihon Expressway Company Ltd.,2-18-19,Nishiki, Naka-ku, Nagoya-shi, Japan, s.kusano.ab@c-nexco.co.jp [2]Civil Enginner, Central Nihon Expressway Company Ltd.,4-3-1, Toranomon, Minato-ku, Tokyo, Japan, n.takahashi.ah@c-nexco.co.jp [3]Associate Professor, Faculty of Regional Environment Science, Tokyo University of Agriculture, 1-1-1, Sakuragaoka, setagaya-ku, Tokyo, Japan, m3yamasa@nodai.ac.jp [4]Road Group, NEWJEC Inc., 2-3-20, Honjo-Higashi, Kita-ku, Osaka, Japan, teraots@newjec.co.jp [5]Technical Support Group, FORUM8 Co.,Ltd., 2-1-1, Kamimeguro, Meguro-ku, Tokyo, Japan, tashiro@forum8.co.jp [6]Road Support Group FORUM8 Co.,Ltd., 2-1-1, Kamimeguro, Meguro-ku, Tokyo, Japan, thea@forum8.co.jp [7]Transportation Planning Team, NEWJEC Inc., 1-12-13 Shin-Ohashi, Koto-ku, Tokyo, Japan, imaimn@newjec.co.jp [8]Road Group, NEWJEC Inc., 1-12-13 Shin-Ohashi, Koto-ku, Tokyo, Japan, fukasetk@newjec.co.jp

Abstract:

In this study, we have made anThis study is an attempt to link OHPASS, Optimal Highway Path Automatic Search System, and three-dimensional (3D) CAD by including the attributes of information such as terrains, geological features, and environments within extended digital mapping (DM) data. In addition, we have constructed a system that links with 3D CAD, and enables output 3D data to be viewed and evaluated on VRas a virtual reality (VR) model. By In linking with 3D VR, its effective use is can be expected in the system can be used for road alignment and landscape planning and evaluation, as well as for presenting project proposals to a wider audience and road structure evaluation at the time of planning road alignment, consensus building with the parties concerned, and at explanatory meetings.

***Key Words :** 3-D CAD, road design, virtual reality, extended digital mapping data*

1. INTRODUCTION

Many studies have been done on the construction of ideal highway alignments that satisfy various demands such as costs and restrictions, and they have contributed to the development of automated models for optimizing highway alignment. As a first step, in developing an automatic optimization model, it was necessary to determin main costs as well as, develop efficient algorithms, and link them to the actual Geographic Information System (GIS). Here "Main costs" refers to the expenditures that make up a high proportion of the total cost. Models for highway alignment optimization seeked to optimize highway alignments by minimizing the total cost.[1][2] It is also suggested that the following characteristics are essential for effective highway alignment optimization models [1] :

(1) Examines all the main costs and variable costs,
(2) Formulates all the important restrictions,
(3) Generates realistic alignments,
(4) Capable of treating alignments accompanied with backward bending,
(5) Optimizes horizontal and vertical alignments at the same time,

(6) Finds the most appropriate solution on or almost on a worldwide scale,
(7) Has efficient solution algorithms,
(8) Has a continuous search space,
(9) Considers the costs for intersections, interchanges, bridges, and tunnels,
(10) Automatically avoids inaccessible areas, and
(11) Has GIS compatibility.

For optimizing highway alignments, various conventional optimization methods have been used, including: the variational method, the dynamic planning method, numerical searching, the alignment planning method, and network optimization (Howard et al, 1968; Thomson and Sykes, 1998; Shaw and Howard, 1981, 1982; OECD, 1973; Turner and Miles, 1971; Turner, 1978; Athanassoulis and Calogero, 1973; Parker, 1977; Trietsch and Handler, 1985; Trietsch, 1987a, b; Hogan, 1973; Nicholson et al., 1976).[2][3][4] However, most of these methods lacked at least one of the highway alignment optimization model characteristics indicated above.

Genetic algorithms have proven to be effective for optimizing highway alignments, Particularly as the optimization of horizontal (planar) and vertical alignments can be performed effectively at the same time.[1][3] This is performed by searching for a better solution through continuous generation as well as by utilizing the whole search space without stopping at a local solution. This algorithm enables optimization of both horizontal and vertical alignments. It is possible to generate a flat and continuous alignment (e.g. not a corridor but an accurate linear shape), while directly linking the generated alignments to an actual GIS map.

The Optimal Highway Path Automatic Search System (OHPASS) has been created for the purpose of performing quantitative evaluation on a large number of alignments that are unable to be examined by conventional road design methods for highway alignment plans.[5][6][7] This study reports a new approach, which has never been published, that visualizes an optimized alignment by linking extended DM data using GIS to OHPASS, as well as by linking 3D-CAD to a VR system at the same time; i.e. constructing a system for highway alignment optimization and landscape simulation.

2. OVERVIEW OF EXTENDED DM (DIGITAL MAPPING)

(1) Problems with using DM data

For road design, topographic map data is frequently used with road design CAD. Since DM (Digital Mapping) data doesn’t require elevation data from benchmarcks, contour lines, or spot elevations, this elevation data will not be reflected in the DM data result, even when a topographic survey observes elevations. It has been problematic that DM data can’t be utilized for road design. In order to solve this problem, specifications of extended DM data have been examined.

(2) DM and extended DM

In "MLIT Work Regulations for Public Surveys" created by Ministry of Land, Infrastructure and Transport (MLIT) [8], specifications for DM data are provided under "Classification Standards for Acquisition of Digital Mapping Data" and "Specifications for Digital Mapping Data Files", which unify interpretations of data file specifications and clarify them. They also extend the specifications of DM data files for applications other than the products of digital terrain surveys, and put together a "Draft Code for Implementation of Extended Digital Mapping". Also, the “Draft Guidelines for Electronic Delivery of Survey Products” provid guidelines for creating a DM data file with these extended DM specifications, applying them as a form of electronic delivery for some of the products of fiducial point surveys and applied surveys in addition to the products of digital terrain surveys. In the “Draft Guidelines”, the specifications provided under the "MLIT Work Regulations for Public Surveys" and the "Draft Code for Implementation of Extended Digital Mapping" are distinguished by naming the former "DM" and the latter "extended DM" respectively (Figure 1).

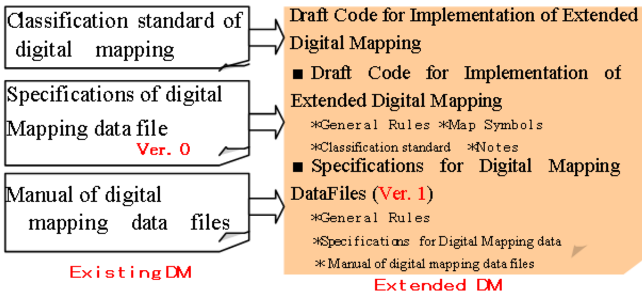

Figure 1: DM and extended DM

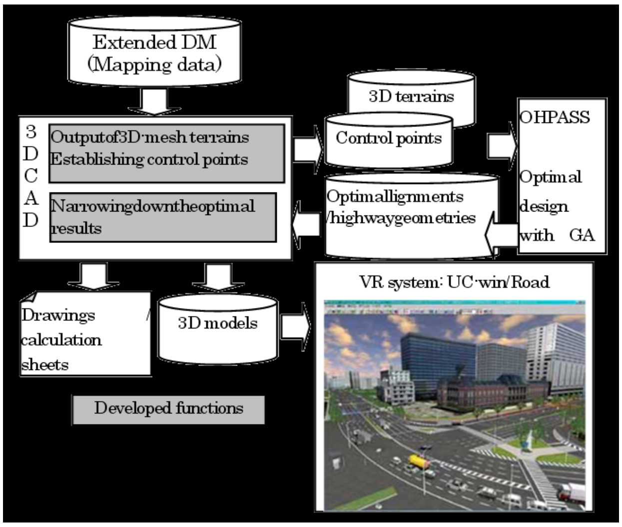

Figure 2: System configuration

The major difference between "DM" and "extended DM" is that the latter can be used for road design purposes. The primary changes includes: 1) unification of interpretation of use and minor modifications, and 2) application to applied surveys, etc. Especially for extended DM, it has been specified that elevation values for contours, elevation points, etc. should be clearly described. Here, regarding terrain expression, there is a different type used by digital terrain models (DTM) in addition to using contours. Work Regulations for Public Survey permit the use of both display types at the same time.

3. 3D-CAD, EXTENDED DM, AND A VR SYSTEM

(1) System Configuration

We have developed a mechanism for creating 3D highway shapes and producing drawings with a data input and creation function in OHPASS. Figure 2 shows the system configuration diagram. This system has been developed based on AutoCAD Civil 3D 2007 (reffered to as Civil 3D), a civil engineering CAD software. The functions developed include a method for creating 3D terrain and control points that are input using Civil 3D, and a function to incorporate the calculated results back into Civil 3D.

Civil 3D has functions that include loading DM, creating 3D representations of terrain, road design (horizontal design, vertical design, and cross-sectional design). Moreover, we attempt to link the system with UC-win/Road Ver.3.2 (produced by FORUM8 Co., Ltd.), one of the 3D-model VR systems. UC-win/Road is capable of providing various real-time presentations with CG after generating three-dimensional VR spaces, and has been utilized for examining landscapes, consulting for design, and presenting project briefings. It also provided the data exchange function with Civil 3D used in this study implemented, enabling linkage experiments to be performed without developing special software.

(2) Data Conversion and the Establishment of Control Points: (OHPASS Input Interface)

In order to efficiently create input data for OHPASS, we developed an interface for converting terrain data, setting up control points, and then passing them into OHPASS.

a) Terrain data conversion function

In OHPASS, terrain is mesh datum. A 2m mesh is required for calculations, while a 20m mesh is required for display. For this reason, we have developed a function to create both 2m and 20m mesh files from a 3D surface model created with Civil 3D. While Civil 3D normally provides an API (Application Program Interface) to export the elevation data of points that are specified in the 3D surface, we have increased the speed and efficiency of this process (e.g. by skipping unnecessary elevations when the file size for terrain data is too large).

b) Control point set-up function

In OHPASS, control points are expressed using lines (for railroads, rivers etc.) or areas (for

houses, prohibited planar areas, etc.). We have developed a function to add the information in OHPASS control points to the lines (unclosed polylines) or poligones (closed polyline) created by the standard CAD functions of Civil 3D.

(3) Loading the Optimal Results (OHPASS Output Interface)

We have developed a function that load the examined results of alignments obtained in OHPASS, and displays them as horizontal and vertical drawings. As a feature of OHPASS, it is possible to examine two or more alignments by changing design conditions; this time, a function for selecting and loading an alignment has been added so that loading can be performed with multiple results examined.

4. DEMONSTRATION EXPERIMENT (USING EXTENDED DM)

(1) Purpose and Procedure

The advantages of using DM include time efficiency in the process of creating terrain data and establishing control points. Working hours are evaluated and, compared with a case where two dimensional terrain CAD data is used .

a) Labor saving in the process of creating 3D terrain data

As the contours include digital elevation data, time taken to create new three dimensional data can be saved. If height information other than contours is required, it is necessary to add the heights separately. However, for topographic maps with a scale of 1 to 2,500, which this system is designed for, it is assumed that the contours will be enough to achieve adequate design accuracy in three dimensional representation.

b) Labor saving in the process of establishing control points

In this study, we have set up control points assuming that extended DM data are classified into layers by map element type and then loaded into the CAD system.

Figure 3 shows the experiment procedure.

1. Road design experts organize evaluation items for the control points that should be considered in designing roads and for the design results.
2. Optimal design calculation is conducted for the actual object.
3. Results are summarized and evaluated.

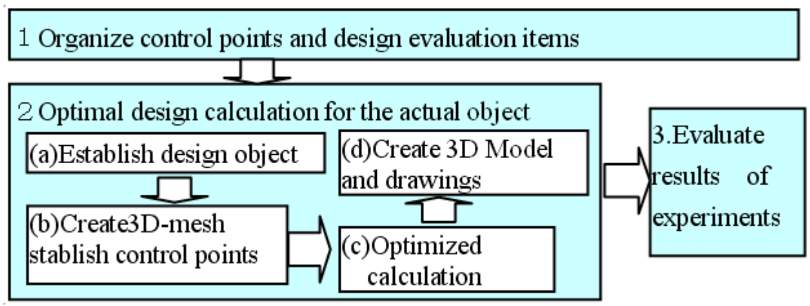

Figure 3: Procedure for optimal highway design using extended DM

In Step 2.("(a)" in Figure 3), difficulties were expected with selecting an object (for which a topographic map had been created with extended DM) out of past design objects. We selected an object for which a topographic map was organized as CAD data, assuming that the DM loading function implemented in this system could be simulated. In (b), we loaded the topographic map for the object selected in (a) into AutoCAD Civil 3D, and edited the layers etc. so that it would be loaded with the DM loading function. This was performed in order to simulate the DM loading function. Next, we created 3D terrains and control points using the newly developed functions. In (c), we specified geometric and earthwork conditions etc., and performed calculations for optimal highway design. In (d), we loaded the results of the optimal design calculation and created a 3D highway model and drawing.

(2) Subject

The object selected as an experimental subject was a highway outline design of a partial section of an Arterial High-Standard Highway. Its overview is as follows:
(a) Designed daily traffic volume (H32): 16,300-21,800 vehicles/day
(b) Highway standard: 1st class, 2nd grade
(c) Design velocity: V=100km/h
(d) Design length: L=21.8km
(e) Structure width: W=20.5m, Four lanes on completion
(f) Design classification: highway outline design (B)
(g) Design year: 2003
(h) Planned as a completed section
(i) Design work has been performed with a plan of S=1/2500

In this demonstration, using the entire section (total length L=21.8km) of the above design object in the experiment would cause a large load to be applied to the computer. Therefore, in consideration of data handling and calculation time, we extracted a section of about 4km and used this as the subject of the experiment.

(3) Creating 3D-Mesh Terrains and Establishing Control Points

Even though it is preferable to conduct an experiment using data with extended DM specifications, as discussed in the experimental procedure, the terrain data for the experimental subject are not extended DM data but CAD data. The reason for this is that current specifications for extended DM are under development and there are no complete data sets in extended DM that can meet product specifications. In order to achieve the purpose of the experiment, we have loaded the terrain data and edited them to the envisioned format of the extended DM. Then, using the edited terrain data, we created a three dimensional terrain mesh and established control points. The procedure and the data created are explained below.

(a) Loading CAD data

Since the CAD data for the subject was in DWG format, the standard format for 3D CAD (Civil 3D), they were loaded without any problem.

(b) Editing the CAD data to simulate DM loading

We edited the loaded data in process (a) so that the data would be in the same condition as they would be in the case of loading extended DM. When using the DM loading function in Civil 3D, data are loaded after being classified into layers according to their map element type. This method is considered common for loading DM data into a CAD system.

In the original CAD data, only the contours had height information. We decided not to provide additional height information because it was assumed that the height data in the DM data output from existing survey work would be contours only. In the highway design under consideration, we had determined that the accuracy would be adequate when the height was given by contours.

(c) Establishing control points

Control points were established using the control point function explained in the above section titled "Linking 3D-CAD, extended DM, and a VR system."

(4) Results of the optimal alignment search

The optimal road alignment calculation system searches for the best alignment within a width of 200m from the left and right extremes of the initial alignment. This time, we searched for three routes, Plan A, B, and C.

Plan A - Northern route: This route passes through a northern area and is optimized with the actual design as the original alignment. It is used to compare the actual design (initial alignment) to the optimal calculation results.

Plan B - Central route: This route makes a southern detour around a natural woodland (environmental protection area) that coexists with a nearby population.

Plan C - Southern route: This route passes through the mountainous area in the south, avoids northern areas that are prone to landslides or considered environmental protection areas.

Figure 4 shows the schematic searching ranges for each plan. The upper drawing of Figure 4 shows the schematic searching ranges while the lower one shows the optimal routes searched through genetc algorithm.

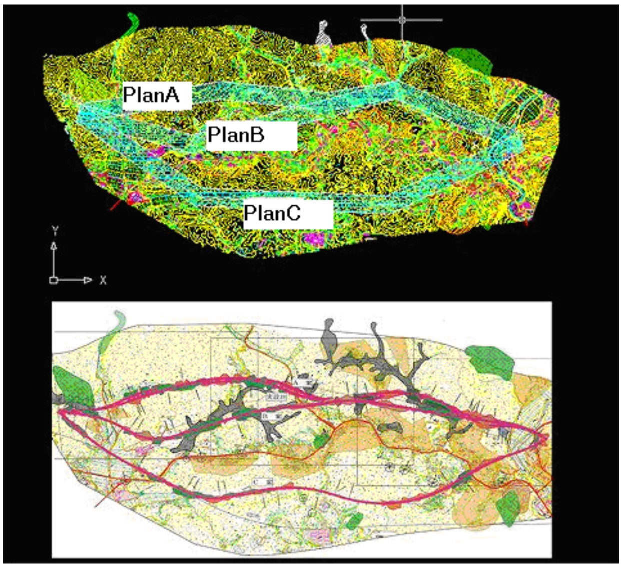

Figure 4: Search range of each route

Table 1 shows a cost comparison. Each of these three plans satisfy the geometric conditions. Plan A is the result of optimization by searching within a range 200m wide on both sides along the initial alignment and combining this with a cost cost analysis. As expected, when comparing the construction cost of the original plan to that of Plan A, Plan A costs less. However, there are still some problems. One problem is that the alignment of the actual design was partially a cross section of a dual carriageway, which was approximated by a single lane. Also, since a section of 4km was extracted out of the total length of 21.8km for the actual design, the volume of earth was not perfectly calculated.

Table 1: Comparison of construction costs

Item		Actualdesign	RouteA	RouteB	RouteC
Length (m)	Earthwork	4,150	4,190	4,270	3,500
	Bridge	230+260+240+300	560+400	400+460	640+380
	Tunnel	0	0	0	900
	Total	5,180	5,150	5,130	5,420
Project costs (1,000,000 yen)	Road (earth work)	24,954	20,529	23,277	16,219
	Bridge	53,923	49,224	51,970	46,343
	Tunnel	0	0	0	39,396
	Others	17,263	17,144	17,632	14,274
	Total	96,140	86,897	92,879	116,232
Alignment element	Minimum curve radius (m)		550	500	550
	Minimum curve length (m)		230	259	308
	Minimum transition curve (m)		550	500	550
	Minimum transition curve length (m)		80	73	71
	Steepest vertical gradient (%)		3.8	4	
	Steepest vertical curve radius (m)		2486	12092	7446
	Steepest vertical curve length (m)		154	472	268

In terms of costs, Plan A, is the least expensive and will be the best option among these three. Also, becase Plan A is the optimal result of the of the initial plan alignment, it verifies the validity of the actual design.

(5) DM Resuts and Problems

This system provides very simple functions such as selecting CAD elements and specifying types of control points. A CAD element is an object such as a line or symbol that describes a feature on a drawing. Even this simple function may automatically reduce an operator's burden as it is easier to edit data that has been separated into layers (in order to establish control points) than to edit uncategorized CAD data. Although we did not measure time the following processes became possible:

(1) Showing only road layers, selecting them as a group, and setting up control points
(2) Hiding elements that have no relation to control points in order to improve visibility

In addition, with the development of more functions in the future, it will be possible to automatically convert a layer into a control point. In other words, when the map elements are drawn in designated layers, elements in each layer will be converted into control points together as a group.

Some problems that inhibit the effective use of the system have also been revealed.

a) Discrepancyof figures

There are some figures for which the figure type for extended DM is different from what is required as a control point. For example, a figure type for extended DM may contain data specifications for creating a map, while a control point for road design indicates things like cultural heritage areas or landslide prone areas. This corresponds mainly to the features represented by map symbols on the side of extended DM.

b)Lack of definition in extended DM

Naturally, some of the control points used in road design were not defined in the extended DM. These problems will be addressed by revising the specifications for the DM on a long-term basis. On a short-term basis, this can be addressed and by examining control points isually as well as by creating data by manual operations in CAD.

5. DEMONSTRATION 2: LANDSCAPE EVALUATION THROUGH LINKAGE WITH A VR SYSTEM

Although roadside landscape is one of the most important considerations for road design, OHPASS does not have a function to evaluate it. In this experiment, a person will judge the landscape using computer graphics (CG). We have linked OHPASS with a VR system and examined its uses and effects. The VR system configuration is described in “Linking 3D-CAD, Extended DM and a VR System: System configuration” section.

(1) Automatic Generation of VR Spaces

Terrain data are loaded from 3D data created within Civil 3D via a LandXML format file. Next, horizontal alignment data for highways (linear coordinates and parameters), vertical alignments (intersection pointst, height, VCL, etc.), and highway cross sections (width of road surface, slope gradient / bench spacing, etc.) are loaded. A three-dimensional space is created by combining all these data. 3D geometries are not loaded directly from 3D CAD data. Instead, VR software is used to load the cross-section data and build its design geometries. The geometry created by the VR software does not differ from from geometry created with 3D CAD software. When creating a 3D VR space, we have also used textures to represent details such as lane markings, road surface textures, and cutting / banking, which is not expressed in the process of 3D modeling. Figure 5 shows the link between the VR and Civil 3D systems.

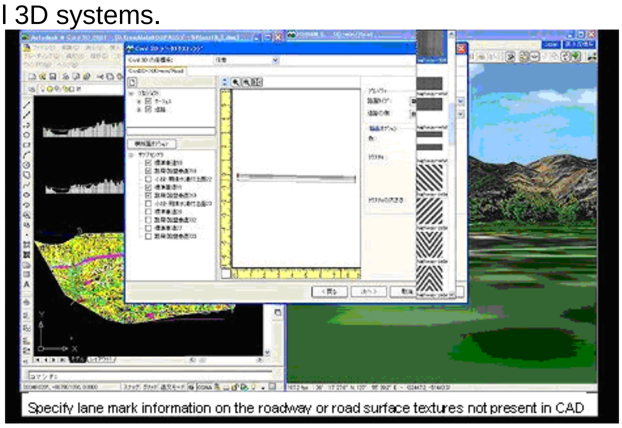

Figure 5: Linkage of CAD and VR system

(2) Evaluation and Discussion

We made a presentation showing an animation with real-time CG. Figure 6 shows the presentation screen. After presentation and examination the following results were achieved:

a) Landscape evaluation from a driver's perspective

The VR simulation can be utilized for examination and evaluation of safety issues such as driver viewing distance and visibility with different alignments. The geometry of cutting and banking and road structure has only a limited effect on drivers. For example, the sense of apprehension that a driver might feel when passing through a steeply cut terrain area can be evaluated to a certain extent. However, for examining the geometry of tunnel entrances, separate model creation apart from the described workflow is necessary for evaluation in the VR space.

b) Effects produced by substantial reduction in time for image generation

Streamlining the image creation process (by loading the extended DM in OHPASS to transferring it into 3D CAD and the VR system) can substantially reduce the working hours that would be required for image generation using a conventional method.

Figure 6: Screen Example for presentation

Table 2 shows the time required for these demonstration experiments. In this case demonstrations 1 and 2 are considered consecutive. Demonstration 1 was performed to search for an optimal alignment with OHPASS using the data converted into the specifications of extended DM. Demonstration 2 used the results produced by OHPASS and linked these with a VR system. In comparing the time required to generate alternative plans: (a) is equal. Yet this system makes it possible to generate alternative plans and preview them with the VR simulation in about 60 minutes, the total working time of steps (b), (c), and (d). For instance, when deciding between an embankment or an elevated structure, after calculating the alignments, the following procedure makes it possible to compare both plans in a short amount of time taking into account construction costs or volume of earthwork.

Table 2: A comparison of working time

	Work contents	Working time required for the conventional method	Working time required for this system
(a)	Creating 3D terrains from DM and establishing control points	240min	240min
(b)	Optimal design calculation with OHPASS	420min	10min
(c)	3D representation of the calculation results from OHPASS	180min	30min
(d)	Creating data with a VR system	240min	20min
	Total	1,080min	300min

(1) Embankment geometry generation with a series of operations up to the VR system

(2) Establishment of an area to be made into an elevated structure as a control point for a "compulsory elevated section" using the function of OHPASS

(3) (b) Optimal design calculation using OHPASS --> (c) three-dimensional representation of the calculation results from OHPASS

(4) (d) Data creation using VR system and comparison with the result of (1)

6. CONCLUSIONS

In this study, we have attempted to link OHPASS, an optimal road alignment search program, with three-dimensional CAD. By creating 3D terrain from extended DM and using a function to establish control points, a basis for utilizing extended DM has been created. In addition, by enabling the optimal design calculation results to be loaded into 3D CAD, graphical representations of the design results have been linked with a VR system.

Using the developed system, we performed demonstrations with the extended DM. It was

concluded that using extended DM is effective for creating three-dimensional terrain models of the present conditions. In order to save time, these models are essential as input data for the optimal design system. Next, we conducted a linkage experiment with a VR system. It was confirmed that it is effective to evaluate landscapes in a short amount of time by utilizing extended DM as input data and linking the optimal highway alignment design system, 3D CAD, and VR system. We expect that a link between OHPASS and a VR system can be used effectively for landscape evaluation during highway alignment design stages, as well as for consensus building and presenting proposals. Also, as a link between UC-win/Road and driving simulator hardware has been created, we can expect that this research may also be useful for advanced driver assistant systems. Issues to be dealt with in the future include finding a way to provide height information for features other than contours in extended DM, creating shape required as control points, and dealing with items not considered in OHPASS.

REFERENCES

1. J.-C. JONG. Optimizing highway alignment with genetic algorithms. Ph.D. dissertation, University of Maryland, College Park, MD. 1998.

2. Manoj Kumar JHA. A geographic information systems-based model for highway design optimization. Ph.D. dissertation, University of Maryland, College Park, MD. 2000.

3. J.-C. JONG and Paul SCHONFELD. An Evolutionary model for simultaneously optimizing three-dimensional highway alignments. Transportation Research, Part B. 2003.

4. AASHOTO. A Manual on User Benefit Analysis of and Bus Transit Improvements. American Association of state Highway and Transportation Officials, Washington, Dc. 1977.

5. Masaya YAMASAKI, Teietsu HONGO, Hiroshi IMAMURA, Kazuo HIYANE, Jun LIO, Tomoyuki YATABE, and Seiichi KAGAYA. Basis study in optimal vertical design with digital terrain data and genetic algorithms. Infrastructure Planning, Collected papers, Vol.18，pp.139-148，2001.

6. Masaya YAMASAKI, Teietsu HONGO, Kazuo. HIYANE, and Tomoyuki YATABE. Study of alignment models for optimizing highway alignments. Collected papers of Japan Society of Civil Engineers, No.758／IV-63，pp.57-69，2004.4.

7. Masaya YAMASAKI, Teietsu HONGO, Kazuo HIYANE, Jun LIO and Tomoyuki YATABE. Genetic Algorithms Based Optimization of Three-Dimensional Alignments for Highways, Proceedings of the Third International Conference on Engineering Computational Technology, 2002.

8. Ministry of Land, Infrastructure, Transport and Tourism: "MLIT Work regulations for public survey". Japan Association of Surveyors, 2002.